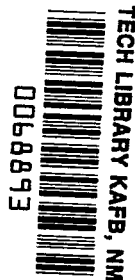


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METHOD OF CALCULATING
LONGWAVE FLUXES IN THE
TROPOSPHERE IN THE CASE
OF A CLOUDLESS SKY

by Ye. P. *Trushkova*

From *Trudy Glavnoy Geofizicheskoy Observatorii
imeni A. I. Voyeykova*, No. 152, 1964



METHOD OF CALCULATING LONGWAVE FLUXES
IN THE TROPOSPHERE IN THE CASE OF A CLOUDLESS SKY

Ye. P. Barashkova

Translation of "K metodike rascheta dlinnovolnovykh
potokov v troposfere pri bezoblachnom nebe."
Trudy Glavnoy Geofizicheskoy Observatorii imeni A.I. Voyeykova
No. 152, pp. 68-80, 1964.

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METHOD OF CALCULATING LONGWAVE FLUXES IN THE TROPOSPHERE IN
THE CASE OF A CLOUDLESS SKY

Ye. P. Barashkova

ABSTRACT

An investigation is made of the correlation of long-wave fluxes computed from the Shekhter diagram for various levels in the troposphere with various meteorological elements. Simple equations are obtained for the descending flux

$$E_{Dz} = 0.76 \sigma T_z^4 W_z^{0.12}$$

and the ascending flux

$$E_{Az} = \sigma T_s^4 \cdot 10^{-0.0036 \Delta t},$$

where W_z is the absorbing mass above the level z , T_z is the air temperature at the level z , and T_s is the temperature of the base surface, $\Delta t = T_s - T_z$.

The obtained equations are verified, and the average variation of E_{Dz} and E_{Az} as a function of altitude is presented for the cloudless sky at Odessa.

In recent years, analysis of synoptic situations over large territories has attracted the attention of investigators to the study of the radiation balance of the atmosphere and of its individual layers. Unfortunately, however, there are only isolated cases for the measurement of the radiation balance and its components at various levels of the atmosphere with altitude devices in the form of airplanes, balloons and radio probes. The methodology of such measurements is insufficiently developed and each series of measurements requires a substantial expenditure of funds. Therefore, up to the present time, computational methods are used to evaluate the radiation balance at various levels in the atmosphere.

To compute the components of the longwave balance some authors have proposed radiation diagrams which make use of temperature probing. According to the data of Kh. Niylik (ref. 1) the most reliable of these diagrams are those of F. N. Shekhter (ref. 2) and of Brooks (ref. 3). The calculations based on the radiation diagrams are reduced to graphic integration; although this is convenient in individual cases it becomes very cumbersome when a large number of calculations are involved.

The question arises as to whether it is possible to use simple equations of the type presented by Brent and Angström (ref. 4) to compute the components of the longwave balance at various levels in the troposphere. These equations relate the longwave fluxes with the temperature and humidity of the air.

Due to the shortcomings of empirical data, we attempted to clarify this question by using the results of calculations in accordance with the Shekhter diagram and compared them with a series of meteorological elements. The calculations were made on the basis of air temperature and humidity data obtained by measurements with radio sounding balloons over Odessa in 1955 for all cases of cloudless sky. In cases where the data from aerological sounding permitted, calculations were made for all altitudes z equal to 0.5, 1.0, 1.5, 2, 3, 4, 5, 6, 7 and 8 km. In this case the methodology presented in reference 5 was used. The emissive power of the base surface was assumed to be equal to unity.

Let us consider separately the ascending and descending fluxes.

It is known that the descending flux magnitude at the base surface (the counter-radiation of the atmosphere) E_D is determined primarily by the air temperature and humidity at this level. By comparing the values of the descending flux E_{Dz} at the altitude z with the air temperature at the same altitude t_z , it follows that E_{Dz} increases in a linear manner with an increase in t_z (fig. 1). The nature of the variation in E_{Dz} when the air temperature changes is retained at all altitudes. The correlation coefficient of the quantities E_{Dz} and t_z is $r = 0.9977 \pm 0.0007$, while the regression equation is

$$E_{Dz} = 0.313 + 0.0085 t_z,$$

where E_{Dz} is expressed in cal/cm² min, while t_z is given in degrees C.

In computing the correlation coefficient and the coefficients of the regression equation we made use of the combination of values of E_{Dz} for all z .

The high correlation coefficient for t_z and E_{Dz} , corresponding to various values of humidity, is explained by a definite relation between the temperature

and the humidity of the air. On the other hand, there is a rather close relation between E_{Dz} and humidity q_z . In this case the correlation ratio is

$\eta = 0.934$, while the equation which relates the average values of E_{Dz} and q_z may be represented in the form

$$E_{Dz} = 0.20 q_z^{0.43},$$

where E_{Dz} is expressed in cal/cm² min., while q_z is expressed in gm/kg.

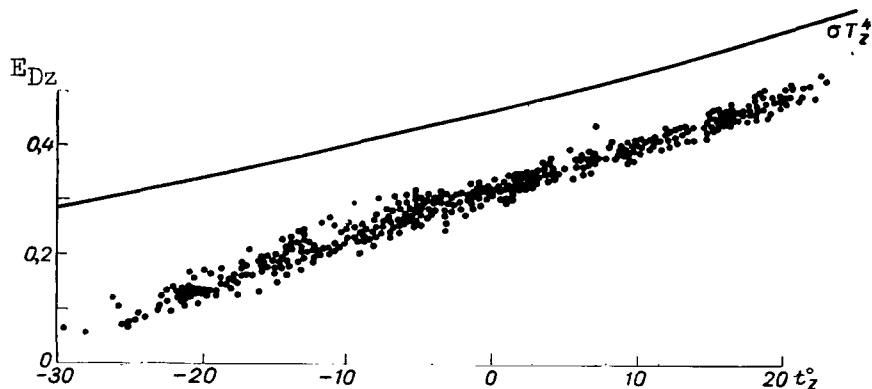


Figure 1. The Relation between the Descending Flux E_{Dz} at the Altitude z and the Temperature of the Air at the Same Altitude t_z .

A somewhat higher correlation ratio $\eta = 0.957$ is noted when we consider the relation between E_{Dz} and the absorbing mass W_z situated above the level z (fig. 2):

$$W_z = \int_z^{\infty} \frac{p}{p_0} q \rho dz.$$

Here q is the specific humidity of the air, ρ is the density of the air and p is the air pressure.

The average relationship between E_{Dz} and W_z is given in the form of a parabola:

$$E_{Dz} = 0.41 W_z^{0.275}.$$

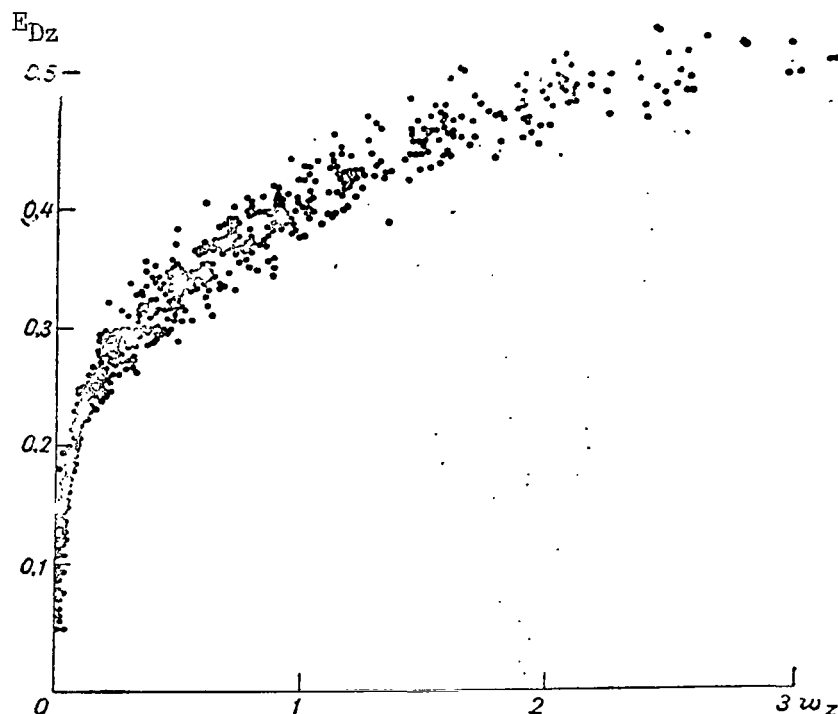


Figure 2. The relation between the Descending Flux E_{Dz} at an Altitude z with the Absorbing Mass W_z Situated Above the Level z .

To eliminate the effect of temperature we considered the ratio $\frac{E_{Dz}}{\sigma T_z^4}$.

This ratio is always less than unity and its magnitude increases as W_z or q increase (figs. 3a and 3b). The correlation ratio of the quantities $\frac{E_{Dz}}{\sigma T_z^4}$ and of the specific humidity q_z constitutes $\eta = 0.806$, while with an absorbing mass W_z $\eta = 0.946$.

On the average

$$\frac{E_{Dz}}{\sigma T_z^4} = 0.76 W_z^{0.12}. \quad (1)$$

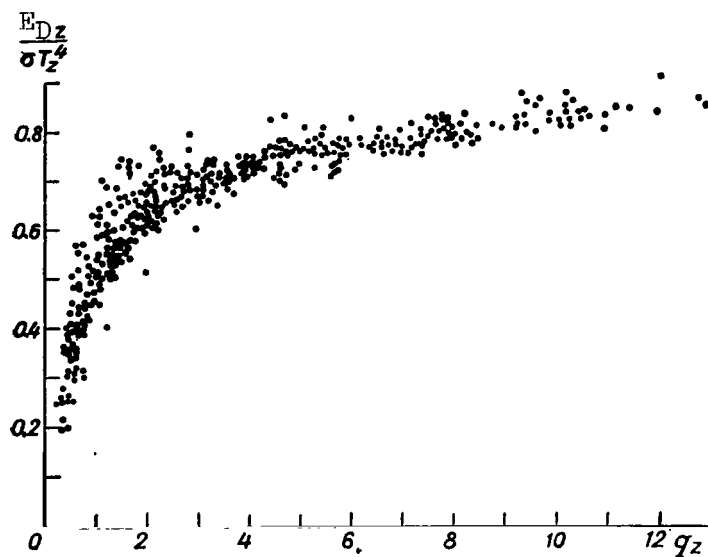


Figure 3a. The Relation between the Ratio $\frac{E_{Dz}}{\sigma T_z^4}$ and the Specific Humidity q_z .

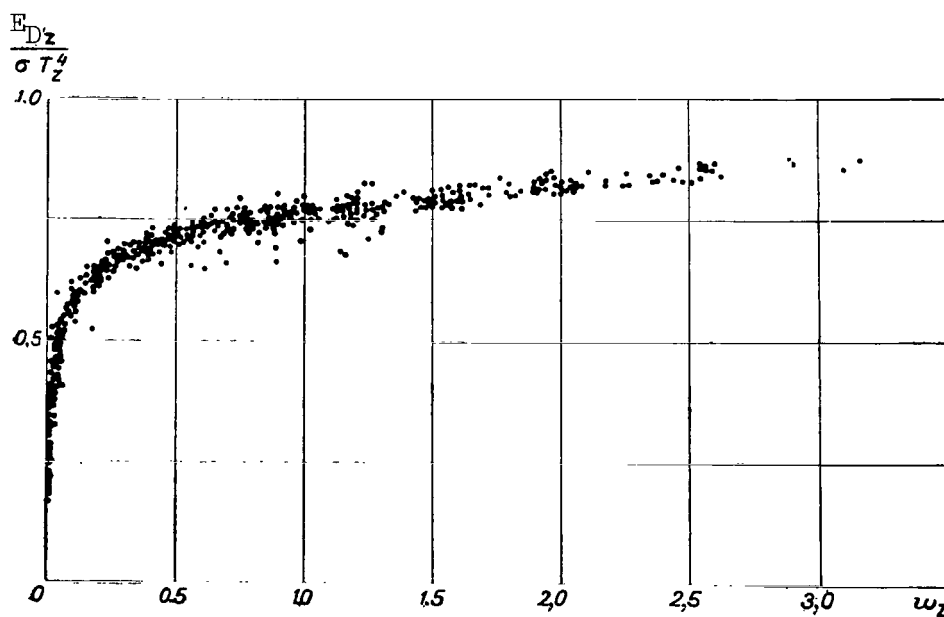


Figure 3b. The Relation between the Ratio $\frac{E_{Dz}}{\sigma T_z^4}$ and the Absorbing Mass w_z .

It should be noted that in the calculation of σT_z^4 we used the value $\sigma = 0.826 \cdot 10^{-10}$ cal/cm²min · degree⁴, while the basis of the radiation diagram which was used to compute the value of E_{Dz} , was $\sigma = 0.842 \cdot 10^{-10}$. Therefore the value of the coefficient which in this case is equal to 0.76 may vary by 1-1.5 percent if other values for σ are used.

Equation (1) makes it possible to represent the magnitude of the descending flux at level z in the form of a product of the radiation of a blackbody at the air temperature at level z and the parabolic function of the absorbing mass W_z , i.e., in a form convenient for carrying out mass calculations. In

this case the value of W_z is computed from the data of aerological sounding by a method presented in reference 5.

TABLE 1.

$0,76 w_z^{0,12}$

| w_z | 0,00 | 0,01 | 0,02 | 0,03 | 0,04 | 0,05 | 0,06 | 0,07 | 0,08 | 0,09 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0,00 | 0,000 | 0,437 | 0,475 | 0,499 | 0,516 | 0,530 | 0,542 | 0,552 | 0,561 | 0,568 |
| 10 | 577 | 583 | 589 | 595 | 601 | 605 | 610 | 615 | 619 | 622 |
| 20 | 626 | 630 | 634 | 637 | 641 | 644 | 647 | 650 | 653 | 655 |
| 30 | 657 | 660 | 663 | 665 | 668 | 670 | 673 | 674 | 677 | 678 |
| 40 | 680 | 682 | 684 | 686 | 688 | 690 | 692 | 694 | 696 | 698 |
| 50 | 699 | 701 | 702 | 704 | 706 | 708 | 709 | 711 | 712 | 713 |
| 60 | 715 | 716 | 717 | 719 | 720 | 721 | 723 | 724 | 726 | 727 |
| 70 | 728 | 729 | 730 | 732 | 733 | 734 | 735 | 736 | 737 | 738 |
| 80 | 740 | 741 | 742 | 743 | 744 | 745 | 747 | 748 | 748 | 749 |
| 90 | 750 | 751 | 752 | 753 | 754 | 755 | 756 | 757 | 758 | 758 |
| 1,00 | 759 | 760 | 761 | 762 | 763 | 764 | 765 | 766 | 767 | 767 |
| 10 | 768 | 769 | 770 | 771 | 772 | 773 | 773 | 774 | 775 | 776 |
| 20 | 776 | 777 | 778 | 779 | 780 | 781 | 782 | 782 | 783 | 784 |
| 30 | 784 | 785 | 786 | 786 | 787 | 788 | 788 | 789 | 790 | 791 |
| 40 | 792 | 792 | 793 | 794 | 794 | 795 | 796 | 796 | 797 | 798 |
| 50 | 798 | 799 | 799 | 800 | 800 | 801 | 802 | 802 | 803 | 803 |
| 60 | 804 | 804 | 805 | 805 | 806 | 807 | 807 | 808 | 809 | 809 |
| 70 | 810 | 810 | 811 | 812 | 812 | 813 | 813 | 814 | 814 | 815 |
| 80 | 815 | 816 | 817 | 817 | 818 | 818 | 819 | 819 | 820 | 820 |
| 90 | 821 | 821 | 822 | 822 | 823 | 823 | 824 | 824 | 825 | 825 |
| 2,00 | 826 | 826 | 827 | 827 | 828 | 828 | 829 | 829 | 830 | 830 |
| 10 | 831 | 831 | 832 | 832 | 833 | 833 | 834 | 834 | 835 | 835 |
| 20 | 836 | 836 | 837 | 837 | 837 | 838 | 838 | 839 | 839 | 840 |
| 30 | 840 | 840 | 841 | 841 | 842 | 842 | 843 | 843 | 844 | 844 |
| 40 | 845 | 845 | 846 | 847 | 847 | 847 | 848 | 848 | 848 | 849 |
| 50 | 849 | 850 | 850 | 851 | 851 | 852 | 852 | 852 | 853 | 853 |
| 60 | 854 | 854 | 854 | 855 | 855 | 855 | 856 | 856 | 857 | 857 |
| 70 | 857 | 857 | 858 | 858 | 858 | 859 | 859 | 859 | 860 | 860 |
| 80 | 860 | 860 | 861 | 861 | 862 | 862 | 862 | 862 | 862 | 863 |
| 90 | 863 | 863 | 863 | 864 | 864 | 864 | 865 | 865 | 865 | 866 |
| 3,00 | 866 | | | | | | | | | |

Note: Commas in these tables represent decimal points.

For convenience of calculation the quantity $0.76 W_z^{0.12}$ was represented in the form of Table 1 in which the input parameter W_z is given every 0.01 gm/cm².

To verify equation (1) the results of computing E_{Dz}^E carried out in accordance with this equation were compared with the results for $E_{Dz}^{S.D.}$ obtained in accordance with the Shekhter diagram. The initial data for the calculations consisted of the results of aerological soundings on specific days in 1957 and 1958 when the sky was cloudless at Arkhangelsk, Minsk, Kiev and Odessa, i.e., at points situated in different climatological zones. A total of 170 pairs of values for E_{Dz} were compared corresponding to different altitudes. For characteristic degree of coincidence of these values we used the magnitude of their

$$\text{ratio } K_1 = \frac{E_{Dz}^E}{E_{Dz}^{S.D.}}$$

In 164 cases out of 170, which constitutes 97 percent of all the considered cases, the deviation E_{Dz}^E from $E_{Dz}^{S.D.}$ did not exceed ± 5 percent, i.e., it lies within the limits of accuracy of the calculations using the diagram. No variation in the ratio K_1 as a function of altitude was noted. Below we present the recurrence of the quantity K_1 :

| K_1 | No. of cases | Percent | K_1 | No. of cases | Percent |
|-------|--------------|---------|-------|--------------|---------|
| <0.95 | 4 | 2.4 | 1.01 | 36 | 21.2 |
| 0.95 | 1 | 0.6 | 1.02 | 34 | 20.0 |
| 0.96 | 2 | 1.2 | 1.03 | 17 | 10.0 |
| 0.97 | 5 | 2.9 | 1.04 | 7 | 4.1 |
| 0.98 | 16 | 9.4 | 1.05 | 1 | 0.6 |
| 0.99 | 22 | 12.9 | >1.05 | 2 | 1.2 |
| 1.00 | 23 | 13.5 | | | |

Thus the proposed equation (1) makes it possible to eliminate measurements with a planimeter when determining E_{Dz} which substantially accelerates the calculation process without loss in accuracy. In this case the most difficult stage is the calculation of the absorbing mass.

To avoid this operation, an attempt was made to use the relation between $\frac{E_{Dz}}{\sigma T_z^4}$ and the specific humidity q_z directly as shown in Table 2.

TABLE 2. THE AVERAGE VARIATION IN $\frac{E_{Dz}}{\sigma T_z^4}$ AS A FUNCTION OF SPECIFIC HUMIDITY q_z .

| q_z | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|-------|------|------|------|------|------|------|------|------|------|------|
| 0.0 | 0.00 | 0.06 | 0.20 | 0.25 | 0.32 | 0.37 | 0.40 | 0.45 | 0.51 | 0.53 |
| 1.0 | 0.55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 |
| 2.0 | 65 | 66 | 66 | 67 | 67 | 68 | 68 | 69 | 69 | 70 |
| 3.0 | 70 | 70 | 71 | 71 | 71 | 72 | 72 | 72 | 72 | 73 |
| 4.0 | 73 | 73 | 73 | 73 | 74 | 74 | 74 | 74 | 75 | 75 |
| 5.0 | 75 | 75 | 75 | 76 | 76 | 76 | 76 | 77 | 77 | 77 |
| 6.0 | 77 | 77 | 78 | 78 | 78 | 78 | 79 | 79 | 79 | 79 |
| 7.0 | 79 | 79 | 79 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| 8.0 | 80 | 81 | 81 | 81 | 81 | 82 | 82 | 82 | 82 | 82 |
| 9.0 | 82 | 82 | 82 | 83 | 83 | 83 | 83 | 83 | 83 | 83 |
| 10.0 | 83 | 84 | 84 | 84 | 84 | 84 | 84 | 85 | 85 | 85 |
| 11.0 | 85 | 85 | 85 | 86 | 86 | 86 | 86 | 86 | 86 | 86 |
| 12.0 | 86 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 |

Below we present the recurrence K_2 : the ratios of the values of E_{Dz} computed on the basis of the average $\frac{E_{Dz}}{\sigma T_z^4}$ as a function of q_z to the values computed in accordance with the Shekhter diagram.

| K_2 | No. of cases | Percent | K_2 | No. of cases | Percent |
|-------|--------------|---------|-------|--------------|---------|
| 0.89 | 6 | 3.5 | 1.01 | 13 | 7.6 |
| 0.90 | 1 | 0.6 | 1.02 | 15 | 8.7 |
| 0.91 | 1 | 0.6 | 1.03 | 15 | 8.7 |
| 0.92 | 2 | 1.2 | 1.04 | 10 | 5.8 |
| 0.93 | 5 | 2.9 | 1.05 | 9 | 5.2 |
| 0.94 | 2 | 1.2 | 1.06 | 6 | 3.5 |
| 0.95 | 8 | 4.6 | 1.07 | 7 | 4.1 |
| 0.96 | 8 | 4.6 | 1.08 | 3 | 1.7 |
| 0.97 | 12 | 7.0 | 1.09 | 2 | 1.2 |
| 0.98 | 11 | 6.4 | 1.10 | 3 | 1.7 |
| 0.99 | 16 | 9.3 | 1.10 | 3 | 1.7 |
| 1.00 | 14 | 8.2 | | | |

From the data presented it follows that when we use the variations in $\frac{E_{Dz}}{\sigma T_z^4}$ as functions of q_z the limits for the variation in the ratio K_2 are substantially extended.

Deviation within the limits ± 5 percent is retained only in 131 of the 172 cases, which constitutes 76 percent of the total number of cases. Thus the use of the latter method of computation leads to some decrease in the accuracy of results but simplifies and accelerates their obtainment. In a series of cases this accuracy may be sufficient.

Now let us analyze the ascending flux E_A . The basic factor which determines the magnitude of the ascending flux is primarily the temperature of the base surface, therefore we should expect a high correlation between the quantities E_{Az} and t_s .

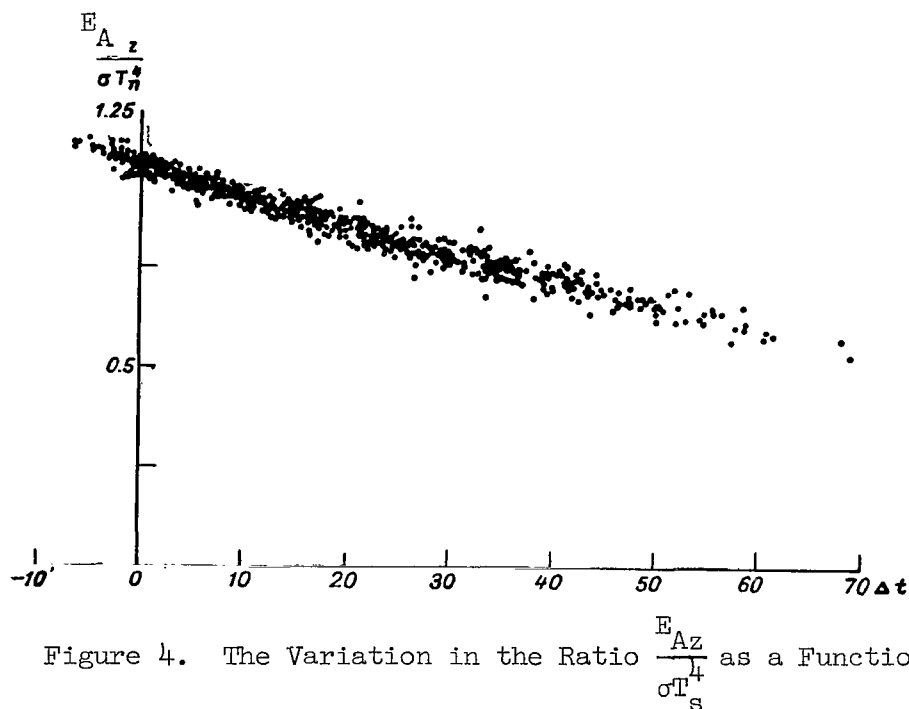


Figure 4. The Variation in the Ratio $\frac{E_{Az}}{\sigma T_s^4}$ as a Function of the

Temperature between the Soil and the Air, Δt .

Up to an altitude of 5 km the correlation ratio of the quantities E_{Az} and t_s is of the order of 0.9; at higher layers it decreases but does not become less than 0.7.

To eliminate the effect of the temperature of the base surface we later considered the quantities $\frac{E_{Az}}{\sigma T_s^4}$, where $T_s = 273 + t_s$. It was established that the variation in $\frac{E_{Az}}{\sigma T_z^4}$ with altitude is associated with the change in the temperature difference $\Delta t = t_s - t_z$. The correlation ratio $\frac{E_{Az}}{\sigma T_s^4}$ and Δt constitutes 0.952.

The relation between $\frac{E_{Az}}{\sigma T_s^4}$ and Δt shown in figure 4 for average values may be expressed by the equation

$$\lg \frac{E_{Az}}{\sigma T_s^4} = -0.0036 \Delta t,$$

from which it follows that

$$E_{Az} = \sigma T_s^4 \cdot 10^{-0.0036 \Delta t}. \quad (2)$$

Thus the calculation of the ascending flux is also reduced to the multiplication of two quantities, one of which is the radiation of a blackbody at the temperature of the base surface, and the other is a function of the temperature difference between the base surface and the air at the considered altitude. For convenience of calculations the latter has been tabulated (Table 3). The use of equation (2) for computing the ascending flux E_{Az} at various altitudes z leads to insignificant deviations from values obtained from the diagram.

K_3 --the ratio of the quantities E_{Az}^E obtained in accordance with equation (2), to the quantities $E_{Az}^{S.D.}$, computed from the diagram--is distributed in the following manner:

| K_3 | No. of cases | Percent | K_3 | No. of cases | Percent |
|-------|--------------|---------|-------|--------------|---------|
| 1.02 | 9 | 5.4 | 0.97 | 9 | 5.4 |
| 1.01 | 25 | 15.0 | 0.96 | 2 | 1.2 |
| 1.00 | 51 | 30.6 | 0.95 | 4 | 2.4 |
| 0.99 | 38 | 22.8 | 0.94 | 5 | 2.8 |
| 0.98 | 21 | 12.6 | 0.93 | 2 | 1.2 |

TABLE 3.

 $10^{-0.0036\Delta t}$

| Δt | 0.0 | -0.1 | -0.2 | -0.3 | -0.4 | -0.5 | -0.6 | -0.7 | -0.8 | -0.9 |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| -10 | 1.086 | | | | | | | | | |
| -9 | 1.077 | 1.078 | 1.079 | 1.080 | 1.081 | 1.082 | 1.082 | 1.083 | 1.084 | 1.085 |
| -8 | 69 | 70 | 70 | 71 | 72 | 73 | 74 | 75 | 75 | 76 |
| -7 | 60 | 61 | 62 | 63 | 64 | 65 | 65 | 66 | 67 | 68 |
| -6 | 51 | 52 | 53 | 54 | 55 | 56 | 56 | 57 | 58 | 59 |
| -5 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 48 | 49 | 50 |
| -4 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 39 | 40 | 41 |
| -3 | 25 | 26 | 26 | 27 | 28 | 29 | 30 | 30 | 31 | 32 |
| -2 | 16 | 17 | 18 | 19 | 19 | 20 | 21 | 22 | 23 | 24 |
| -1 | 08 | 09 | 10 | 11 | 11 | 12 | 13 | 13 | 14 | 15 |
| 0 | 00 | 01 | 02 | 02 | 03 | 04 | 05 | 06 | 07 | 08 |
| Δt | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 1.000 | 0.999 | 0.998 | 0.997 | 0.996 | 0.995 | 0.994 | 0.993 | 0.992 | 0.991 |
| 1 | 0.991 | 90 | 89 | 88 | 88 | 87 | 86 | 85 | 85 | 84 |
| 2 | 84 | 83 | 82 | 80 | 79 | 79 | 78 | 77 | 77 | 76 |
| 3 | 75 | 74 | 73 | 73 | 72 | 71 | 70 | 70 | 69 | 68 |
| 4 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 61 | 60 |
| 5 | 59 | 58 | 57 | 57 | 56 | 55 | 54 | 54 | 53 | 52 |
| 6 | 51 | 50 | 49 | 48 | 48 | 47 | 46 | 45 | 45 | 44 |
| 7 | 44 | 43 | 42 | 41 | 40 | 40 | 39 | 38 | 37 | 36 |
| 8 | 35 | 34 | 34 | 33 | 33 | 32 | 31 | 30 | 30 | 29 |
| 9 | 29 | 28 | 27 | 27 | 26 | 25 | 24 | 23 | 22 | 21 |
| 10 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 13 |
| 11 | 12 | 12 | 11 | 10 | 10 | 09 | 08 | 07 | 07 | 06 |
| 12 | 06 | 05 | 04 | 03 | 02 | 01 | 01 | 00 | 899 | 898 |
| 13 | 897 | 896 | 896 | 895 | 894 | 894 | 893 | 892 | 892 | 891 |
| 14 | 91 | 90 | 89 | 88 | 88 | 87 | 86 | 85 | 85 | 84 |
| 15 | 83 | 82 | 81 | 81 | 80 | 79 | 78 | 78 | 77 | 76 |
| 16 | 75 | 75 | 74 | 74 | 73 | 72 | 71 | 71 | 70 | 69 |
| 17 | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 63 | 62 | 62 |
| 18 | 61 | 61 | 60 | 59 | 58 | 58 | 57 | 56 | 56 | 55 |
| 19 | 55 | 54 | 53 | 52 | 51 | 50 | 50 | 49 | 48 | 48 |
| 20 | 47 | 47 | 46 | 45 | 45 | 44 | 43 | 43 | 42 | 41 |
| 21 | 40 | 40 | 39 | 38 | 38 | 37 | 37 | 36 | 35 | 34 |
| 22 | 34 | 33 | 33 | 32 | 31 | 30 | 30 | 29 | 28 | 27 |
| 23 | 27 | 26 | 26 | 25 | 24 | 24 | 23 | 22 | 22 | 21 |
| 24 | 20 | 19 | 18 | 18 | 17 | 17 | 16 | 16 | 15 | 14 |
| 25 | 13 | 13 | 12 | 11 | 10 | 09 | 09 | 08 | 08 | 07 |
| 26 | 06 | 05 | 04 | 04 | 03 | 03 | 02 | 02 | 01 | 00 |
| 27 | 799 | 798 | 798 | 797 | 797 | 796 | 795 | 795 | 794 | 793 |
| 28 | 92 | 92 | 91 | 91 | 90 | 89 | 89 | 88 | 88 | 87 |
| 29 | 87 | 86 | 86 | 85 | 84 | 84 | 83 | 83 | 82 | 81 |
| 30 | 80 | 79 | 78 | 78 | 77 | 77 | 76 | 75 | 74 | 74 |
| 31 | 73 | 72 | 72 | 71 | 71 | 70 | 69 | 68 | 68 | 67 |
| 32 | 67 | 66 | 65 | 65 | 64 | 64 | 63 | 62 | 62 | 61 |
| 33 | 60 | 59 | 58 | 58 | 57 | 57 | 56 | 56 | 55 | 55 |
| 34 | 54 | 54 | 53 | 52 | 52 | 51 | 50 | 50 | 49 | 48 |
| 35 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 42 | 42 | 41 |
| 36 | 41 | 41 | 40 | 39 | 39 | 38 | 37 | 37 | 36 | 36 |
| 37 | 36 | 35 | 34 | 33 | 33 | 32 | 32 | 32 | 31 | 31 |
| 38 | 30 | 29 | 28 | 28 | 27 | 27 | 26 | 25 | 25 | 24 |
| 39 | 24 | 23 | 22 | 22 | 21 | 20 | 20 | 19 | 19 | 18 |
| 40 | 18 | 18 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 |
| 41 | 11 | 11 | 10 | 10 | 09 | 08 | 08 | 07 | 07 | 06 |

TABLE 3. - Continued

| Δt | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|------------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 42 | 06 | 05 | 05 | 04 | 04 | 03 | 03 | 02 | 02 | 01 |
| 43 | 700 | 700 | 699 | 698 | 698 | 697 | 697 | 696 | 696 | 695 |
| 44 | 695 | 694 | 693 | 692 | 692 | 692 | 691 | 691 | 690 | 690 |
| 45 | 89 | 88 | 88 | 87 | 86 | 85 | 85 | 84 | 83 | 83 |
| 46 | 82 | 82 | 82 | 81 | 80 | 80 | 79 | 79 | 78 | 78 |
| 47 | 77 | 77 | 76 | 76 | 75 | 74 | 73 | 73 | 72 | 72 |
| 48 | 71 | 71 | 70 | 70 | 69 | 69 | 68 | 68 | 68 | 67 |
| 49 | 67 | 66 | 66 | 65 | 65 | 64 | 64 | 63 | 62 | 62 |
| 50 | 61 | 61 | 60 | 60 | 59 | 58 | 58 | 57 | 57 | 56 |
| 51 | 55 | 55 | 54 | 54 | 53 | 53 | 52 | 52 | 51 | 51 |
| 52 | 50 | 50 | 49 | 49 | 48 | 48 | 47 | 47 | 46 | 46 |
| 53 | 45 | 45 | 44 | 44 | 43 | 43 | 42 | 42 | 41 | 41 |
| 54 | 40 | 40 | 39 | 39 | 38 | 38 | 37 | 36 | 36 | 35 |
| 55 | 34 | 34 | 33 | 32 | 31 | 31 | 30 | 30 | 29 | 29 |
| 56 | 28 | 28 | 27 | 27 | 26 | 26 | 25 | 25 | 24 | 24 |
| 57 | 23 | 23 | 22 | 22 | 21 | 21 | 20 | 20 | 19 | 19 |
| 58 | 0.618 | | | | | | | | | |

The values of E_{AZ} computed by two different methods coincide within an accuracy of ± 2 percent in 144 cases out of 167, which constitutes 86 percent of all the cases. Coincidence with an accuracy of 3 percent is noted in 92 percent of all the cases. The lowering of the ratio $K_3 < 0.98$ is observed principally for altitudes of 8 km.

The longwave balance F obtained as the difference of two quantities is determined with a lesser accuracy. The maximum relative error in the determination of $F = E_D - E_A$ is noted at low altitudes where the quantity F is predominantly of small value. Thus, in the layer adjoining the Earth at an altitude of 0.5 km, the ratio of the longwave balance computed on the basis of equations (1) and (2) to the values computed from the diagram varies from 0.85 to 1.23, while at an altitude of 4 km it varies from 0.90 to 1.07.

For the entire combination of altitudes the ratio $K_4 = \frac{F^E}{F^{S.D.}}$ varies in the following manner:

| K_4 | No. of cases | Percent | K_4 | No. of cases | Percent |
|-----------|--------------|---------|-----------|--------------|---------|
| < 0.85 | 6 | 3.7 | 1.01-1.05 | 27 | 16.7 |
| 0.85-0.90 | 15 | 9.9 | 1.06-1.10 | 17 | 10.5 |
| 0.91-0.95 | 38 | 23.4 | 1.11-1.15 | 4 | 2.5 |
| 0.96-1.00 | 49 | 30.2 | > 1.15 | 5 | 3.1 |

The coincidence of the results with an accuracy up to ± 5 percent is noted in 85 cases, which represents 52 percent of the total cases, while with an accuracy of ± 10 percent it is noted in 135 cases (85 percent), and with an accuracy up to ± 15 percent it is noted in 151 cases (91 percent).

It follows that the proposed equations (1) and (2) represent with sufficient accuracy the results of the calculations in accordance with the Shekhter diagram both for the ascending and descending fluxes. The question arises as to how accurately these equations and the diagram represent the true distribution of radiation.

In many works concerned with the base surface a sufficiently accurate coincidence of measured and computed data is noted. However, as the altitude increases, as pointed out by V. L. Gayevskiy (ref. 6), the agreement between measured and computed values is disrupted. The measured quantities--this refers both to the ascending and descending fluxes--are greater than those obtained from the diagram. The discrepancy increases with altitude and reaches a value of 18-22 percent at 6 km.

Conversely, the data of S. S. Geygerov and V. G. Kastrov (ref. 7) indicate good agreement between the measured and computed values for the longwave balance at all altitudes.

At the present time we do not have enough data to arrive at definite conclusions concerning the agreement or disagreement of measured and computed quantities.

The values of longwave fluxes obtained by us, together with the study of their relation with the meteorological elements, may be used to analyze the variation in the components of longwave balance with altitude. For this purpose we considered separately the case corresponding to the summer and winter period, both for daytime and nighttime.

From Table 4 which shows the variation in the quantities E_{Dz} , E_{Az} , F_z , t_z , q_z , W_z as a function of altitude we can see that in the summer period in the daytime the ascending flux E_{Az} is a decreasing function of altitude. The largest gradients are noted in the lower kilometer layer. The average values of the gradients are as follows:

| Layer in km | $\frac{dE_{Az}}{dz}$ cal/cm ² min km |
|-------------|---|
| 0.0-0.5 | 0.12 |
| 0.5-1.0 | 0.06 |
| 1.0-1.5 | 0.04 |
| 1.5-2.0 | 0.04 |

TABLE 4. THE VARIATION IN THE COMPONENTS OF THE LONGWAVE BALANCE AS A FUNCTION OF ALTITUDE FOR A CLOUDLESS SKY.

| | z KM | | | | | | | | | | |
|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 0.04 | 0.50 | 1.00 | 1.50 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 |
| Summer, daytime (14 cases) | | | | | | | | | | | |
| E_{AZ} | 0.742 | 0.678 | 0.650 | 0.626 | 0.607 | 0.580 | 0.557 | 0.534 | 0.518 | 0.486 | 0.446 |
| E_{DZ} | 0.523 | 0.490 | 0.452 | 0.419 | 0.384 | 0.342 | 0.298 | 0.246 | 0.193 | 0.136 | |
| F_z | 0.219 | 0.188 | 0.198 | 0.207 | 0.223 | 0.238 | 0.259 | 0.288 | 0.325 | 0.350 | |
| t_z | 24.0 | 20.8 | 17.2 | 13.4 | 10.1 | 4.7 | -0.6 | -5.9 | -12.3 | -19.3 | -26.4 |
| q_z | 8.9 | 7.3 | 6.1 | 5.1 | 3.6 | 3.2 | 2.3 | 1.6 | 1.0 | 0.6 | 0.3 |
| w_z | 2.000 | 1.628 | 1.260 | 0.970 | 0.738 | 0.434 | 0.232 | 0.117 | 0.055 | 0.022 | |
| Summer, nighttime (17 cases) | | | | | | | | | | | |
| E_{AZ} | 0.608 | 0.616 | 0.604 | 0.584 | 0.567 | 0.545 | 0.521 | 0.495 | 0.476 | 0.449 | 0.418 |
| E_{DZ} | 0.501 | 0.480 | 0.448 | 0.414 | 0.384 | 0.337 | 0.299 | 0.242 | 0.173 | 0.115 | |
| F_z | 0.107 | 0.136 | 0.156 | 0.170 | 0.183 | 0.208 | 0.222 | 0.253 | 0.303 | 0.334 | |
| t_z | 17.8 | 18.1 | 15.5 | 11.7 | 8.5 | 2.9 | -2.5 | -8.5 | -14.9 | -25.0 | -26.4 |
| q_z | 9.8 | 8.9 | 7.5 | 6.1 | 5.1 | 3.8 | 2.5 | 1.6 | 1.1 | 0.6 | 0.4 |
| w_z | 2.300 | 1.782 | 1.390 | 1.054 | 0.801 | 0.446 | 0.225 | 0.109 | 0.043 | 0.013 | |
| Winter, daytime (3 cases) | | | | | | | | | | | |
| E_{AZ} | 0.476 | 0.494 | 0.490 | 0.492 | 0.472 | 0.439 | 0.419 | 0.399 | | | |
| E_{DZ} | 0.360 | 0.336 | 0.318 | 0.294 | 0.268 | 0.215 | 0.166 | 0.095 | | | |
| F_z | 0.116 | 0.158 | 0.162 | 0.198 | 0.204 | 0.224 | 0.253 | 0.304 | | | |
| t_z | 3.6 | 0.1 | -0.7 | -2.4 | -4.7 | -10.1 | -16.6 | -22.6 | -30.0 | | |
| q_z | 3.6 | 2.9 | 5.2 | 2.0 | 1.6 | 0.9 | 0.5 | 0.3 | 0.2 | | |
| w_z | 0.720 | 0.540 | 0.392 | 0.273 | 0.187 | 0.082 | 0.033 | 0.008 | | | |
| Winter, nighttime (13 cases) | | | | | | | | | | | |
| E_{AZ} | 0.440 | 0.460 | 0.460 | 0.441 | 0.437 | 0.426 | 0.410 | 0.398 | | | |
| E_{DZ} | 0.340 | 0.326 | 0.310 | 0.288 | 0.266 | 0.228 | 0.172 | 0.138 | | | |
| F_z | 0.100 | 0.134 | 0.150 | 0.153 | 0.171 | 0.198 | 0.238 | 0.260 | | | |
| t_z | -2.1 | -2.1 | -2.8 | -4.6 | -6.8 | -10.9 | -16.1 | -21.0 | -25.6 | | |
| q_z | 2.9 | 2.9 | 2.5 | 2.1 | 1.7 | 1.2 | 0.7 | 0.5 | 0.3 | | |
| w_z | 0.760 | 0.580 | 0.437 | 0.314 | 0.226 | 0.114 | 0.045 | 0.021 | | | |

Starting with an altitude of 3 km there is a linear decrease in E_{AZ} with altitude, which is of the order of $0.03 \text{ cal/cm}^2 \text{ min km}$. On different days, depending on the stratification of the atmosphere, the magnitude of the gradients

may deviate from those presented above. However, the general nature of the variation in E_{Az} with z is retained.

A somewhat different picture for the variation of E_{Az} with altitude is observed for the lower layers of the troposphere during the night. In the lower-half layer there is an insignificant increase; in higher layers as in the daytime, E_{Az} decreases with altitude, and starting with an altitude of 3 km the variation in E_{Az} as a function of z is linear. The nighttime values of E_{Az} at all altitudes are lower than the daytime values. The maximum difference between the nighttime and daytime values of E_{Az} is observed in the lower layers where it reaches a value of $0.14 \text{ cal/cm}^2\text{min.km}$. Starting with an altitude of 1 km this difference is almost constant with altitude and constitutes approximately $0.04 \text{ cal/cm}^2\text{min.km}$.

During the winter night the increase in E_{Az} with altitude in the lower layers is exhibited more clearly and extends to an altitude of 1 km. During the winter day, contrary to the summer period, in the lower layer up to an altitude of 1.5 km, there is also some increase in E_{Az} . (We had at our disposal only three cases for this period). The daytime values as before are greater than the nighttime values.

Thus, the vertical distribution of E_{Az} experiences seasonal as well as diurnal variations.

As far as the descending flux E_{Dz} is concerned, there is a decrease in E_{Dz} with altitude over the entire thickness of the troposphere regardless of the season or time of day. There is only some variation in the gradients $\frac{dE_{Dz}}{dz}$.

Thus, for example, in the daytime of the summer period in the lower 2 km layer the gradient $\frac{dE_{Dz}}{dz}$ is approximately equal to $0.08 \text{ cal/cm}^2\text{min.km}$. In the 2 to 5 km layer there is a change in the gradient up to $0.05 \text{ cal/cm}^2\text{min.km}$, while from 5 km, $\frac{dE_{Dz}}{dz}$ again increases up to a value of $0.06 \text{ cal/cm min.km}$. At nighttime in the lower 2 km layer there is some very insignificant (by $0.01 - 0.02 \text{ cal/cm}^2\text{min.km}$.) decrease in E_{Dz} and in the gradient $\frac{dE_{Dz}}{dz}$ compared with their daytime values.

During the winter day in the lower 1-1/2 km layer $\frac{dE_{Dz}}{dz}$ is 0.05 cal/cm²min. km.; above 4 km. it is 0.04 cal/cm²min.km. During the night in the lower layer $\frac{dE_{Dz}}{dz}$ decreases to 0.03 cal/cm²min.km.

The difference in the quantities E_{Dz} during the day and night is very insignificant; the transition from the summer season to the winter season produces a change in E_{Dz} by an amount of 0.16 cal/cm²min.km at the layer close to the Earth and by 0.12 cal/cm²min. km at higher altitudes.

The variation in gradients $\frac{dE_{Dz}}{dz}$ is noted at the same altitudes as the variation in the gradients of the temperature.

As a rule the longwave balance increases with altitude. An exception to this is during the summer day, where in the layer close to the ground from 0 to 0.5 km, (where we observe a super-adiabatic gradient of t_z) there is a decrease in F.

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